Polar Geosci , 11, 200-207, 1998

PRELIMINARY ^{40}Ar-^{39}Ar ANALYSES OF IGNEOUS AND METAMORPHIC ROCKS FROM THE NAPIER COMPLEX

Yutaka TAKIGAMI[1], Naoto ISHIKAWA[2] and Minoru FUNAKI[3]

[1]*Kanto Gakuen University, 200 Fujiagu, Ohta 373-8515*
[2]*School of Earth Sciences, IHS, Kyoto University, Sakyo-ku, Kyoto 606-8501*
[3]*National Institute of Polar Research, Kaga 1-chome, Itabashi-ku, Tokyo 173-8515*

Abstract. Ages of two gneisses and two dolerite dykes which were collected for a paleomagnetic study from Mt Riiser-Larsen in the Napier Complex, East Antarctica, were analyzed by the ^{40}Ar-^{39}Ar method All samples contain excess Ar Based on their age spectra, however, ages of about 800–1100 Ma which are similar to those of Amundsen dykes have been estimated for the dolerite samples One gneiss indicates an age of about 2000 Ma as the upper limit This age might correspond to a thermal event which has not been reported

key words ^{40}Ar-^{39}Ar age, Napier Complex, Amundsen dyke

1. Introduction

The Napier Complex of Enderby Land, East Antarctica, is composed of mainly high temperature metamorphic rocks. Very old U-Pb zircon ages such as 3.9 Ga have been reported for it (BLACK *et al.*, 1986) Hence, this complex has a possibility to give us very important information about the early history of the earth However, the Napier Complex has been known to have also experienced three major thermal events of high pressure and temperature at 3.1 Ga, 2 9 Ga and 2.5 Ga (JAMES and BLACK, 1981, BLACK and JAMES, 1983; BLACK and MCCULLOCH, 1987; SHERATON *et al.*, 1987, BLACK *et al.*, 1992 , OWADA *et al.*, 1994, TAINOSHO *et al.*, 1997) Moreover, in this area, there are many dykes called Amundsen dykes whose ages have been reported to be about 1190 Ma and 2350 Ma (SHERATON and BLACK, 1981; BLACK and JAMES, 1983) Such metamorphic events and thermal activities of dykes seem to have affected the paleomagnetic and age results seriously (FUNAKI, 1984, 1988, ISHIKAWA and FUNAKI, 1997, 1998, UENO, 1995) Paleomagnetic studies were performed for samples which were collected from the Napier Complex during the 35th Japanese Antarctic Research Expedition (ISHIKAWA and FUNAKI, 1997, 1998). We have tried to determine ^{40}Ar-^{39}Ar ages of four samples which we used for paleomagnetic studies.

2. Samples

Igneous and metamorphic rocks were collected at eight sites from the Mt Riiser-

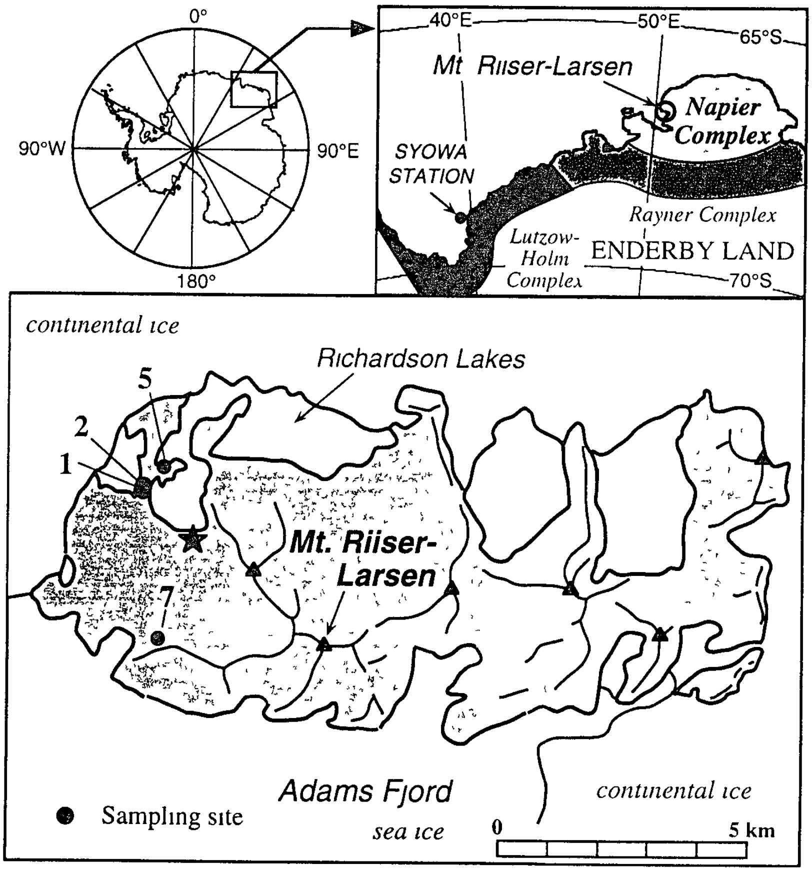

Fig 1 Sampling sites for samples S-1, S-2, S-5 and S-7 (after ISHIKAWA and FUNAKI, 1997)

Larsen area in Enderby Land, East Antarctica by ISHIKAWA for paleomagnetic studies (Fig. 1). Four samples (S-1, S-2, S-5 and S-7) from sites 1, 2, 5 and 7, having relatively good paleomagnetic results (ISHIKAWA and FUNAKI, 1997, 1998), were selected for ^{40}Ar-^{39}Ar geochronological studies. In this study, bulk samples were used for ^{40}Ar-^{39}Ar analyses.

S-1 and S-2 are felsic gneisses consisting mainly of plagioclase, K-feldspar, quartz and clinopyroxene. These sites are situated in a shear zone identified by geological investigation of JARE-38 (ISHIZUKA *et al.*, 1998) and intense mylonitization is clearly observed for these samples.

S-5 and S-7 are metadolerites composed of plagioclase, clinopyroxene. Biotite and amphibole are recognized for S-7. These samples have preserved igneous textures. Since mafic minerals of S-7 are less altered than those of S-5, S-7 seems to be more fresh than S-5.

More details about sampling sites and their petrography are reported in ISHIKAWA and FUNAKI (1997, 1998).

3. Experiments

Rock samples were crushed by a stainless steal crusher. The sieved fractions from 30 mesh to 60 mesh were washed with acetone using an ultrasonic bath and dried in an oven. They were wrapped in Al foil and sealed in a quartz tube of 10 mm diameter under the vacuum condition of about 10^{-1} Pa with age standard samples (EB-1 biotite separated from the standard granitic rock JG-1 of Geological Survey of Japan; age is 91.4±0 5 Ma (Iwata, 1998)), K_2SO_4 and CaF_2 K_2SO_4 and CaF_2 are used to determine the correction factors to correct for interference Ar isotopes derived from K and Ca during the neutron irradiation.

These materials in a quartz tube were irradiated by fast neutrons (total flux was about 10^{18} neutrons/cm^2) at the Japan Material Testing Reactor (JMTR) After cooling, the irradiated samples were transported to the Radio Isotope Centre, University of Tokyo, where Ar gas extraction and analyses were performed

Each sample was set in a Mo crucible and Ar gas was extracted using an induction coil. After being purified with three Ti getters and a SORB-AC getter (ULVAC Corp.), Ar gas was analyzed on a highly sensitive mass spectrometer, VG-3600 (Micromass), which was a sector type mass spectrometer with two collectors (a Faraday cup and a Daly multiplier) Ar isotopes were measured and ages were calculated by comparison of the $^{40}Ar^{*}/^{39}Ar_K$ ($^{40}Ar^{*}$, radiogenic ^{40}Ar, $^{39}Ar_K$, K-derived ^{39}Ar) with those of age standard samples after corrections of mass fractionation and interfering isotopes derived from K and Ca

Table 1 Analytical data of ^{40}Ar-^{39}Ar studies

Sample S-1 (0 0979 g, J=0 00413±0 00003)

No of step	Temperature (℃)	^{40}Ar ($\times 10^6$ cm^3/g)	$^{36}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{37}Ar/^{40}Ar$ ($\times 10^{-3}$)	$^{38}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{39}Ar/^{40}Ar$ ($\times 10^{-3}$)	$^{40}Ar^{*}/^{39}Ar_K$ $^{(1)}$	$^{39}Ar_K$ (%)	Age$^{(2)}$ (Ma)	K/Ca$^{(3)}$
1	600	1 58	1 751	1 769	0 6306	0 4444	2140	0 6	4125	0 2504
			±0 022	±0 024	±0 0053	±0 0131	±63		±49	
2	700	1 20	0 6296	3 049	0 8575	1 168	842 3	1 2	2705	0 3823
			±0 0231	±0 029	±0 0069	±0 006	±4 5		±13	
3	800	2 68	0 7018	4 708	1 261	2 014	487 3	4 8	1989	0 4270
			±0 0129	±0 033	±0 007	±0 007	±1 7		±10	
4	900	2 92	3 492	7 943	2 902	4 007	224 3	10 4	1183	0 5037
			±0 025	±0 047	±0 016	±0 009	±0 5		±7	
5	1000	2 32	1 328	16 58	3 407	5 694	169 4	11 7	1957	0 3426
			±0 019	±0 11	±0 018	±0 011	±0 3		±6	
6	1100	5 76	0 4564	10 08	1 663	2 823	350 7	14 4	1615	0 2793
			±0 0088	±0 06	±0 010	±0 008	±1 0		±8	
7	1200	27 2	0 1494	3 936	0 5145	0 8724	1146	21 0	3150	0 2209
			±0 0033	±0 025	±0 0034	±0 0032	±4		±12	
8	1300	73 8	0 1181	3 721	0 2245	0 3630	2767	23 6	4546	0 09680
			±0 0022	±0 023	±0 0019	±0 0028	±22		±18	
9	1500	58 1	0 1380	5 603	0 1724	0 2452	4133	12 4	5222	0 4300
			±0 0096	±0 149	±0 0046	±0 0090	±154		±65	

Sample S-2 (0 0961 g, J=0 00422±0 00003)

No of step	Tempe-rature (℃)	^{40}Ar ($\times 10^6$ cm^3/g)	^{36}Ar/^{40}Ar ($\times 10^{-4}$)	^{37}Ar/^{40}Ar ($\times 10^{-3}$)	^{38}Ar/^{40}Ar ($\times 10^{-4}$)	^{39}Ar/^{40}Ar ($\times 10^{-3}$)	^{40}Ar*/ ^{39}Ar$_K$	^{39}Ar$_K$ (%)	Age (Ma)	K/Ca
1	600	20 0	0 5972	0 1087	0 1431	0 04576	21500	1 4	8153	0 4201
			±0 0064	±0 0105	±0.0022	±0 00585	±2756		±229	
2	700	5 12	0 4978	0 3923	0 3805	0 5522	1785	4 3	3868	1 407
			±0 0040	±0 0124	±0 0070	±0 0044	±14		±17	
3	800	5 54	2 027	1 194	1 114	1 402	670 9	11 9	2423	1 174
			±0 015	±0 012	±0 012	±0 004	±1 8		±10	
4	900	2 48	1 211	2 093	1 250	2 196	439 4	8 3	1892	1 049
			±0 012	±0 443	±0 034	±0 005	±1 1		±9	
5	1000	2 77	0 8133	2 450	0 9456	1 838	531 7	7 8	2123	0 7493
			±0 0126	±0 226	±0 0390	±0 005	±1 5		±10	
6	1100	3 69	0 6359	2 236	0 8290	1 696	579 1	9 6	2231	0 7578
			±0 0102	±0 221	±0 0411	±0 006	±2 0		±10	
7	1200	5 72	0 3945	2 202	1 014	2 090	473 3	18 3	1980	0 9486
			±0 0086	±0 194	±0 037	±0 006	±1 3		±9	
8	1300	19 7	0 3104	0 9905	0 3741	0 7149	1388	21 6	3473	0 7210
			±0 0039	±0 0113	±0 0142	±0 0059	±12		±17	
9	1500	56 6	0 3358	0 5322	0 1264	0 1941	5111	16 8	5623	0 3640
			±0 0034	±0 0062	±0 0092	±0 0036	±97		±35	

Sample S-5 (0 1088 g, J=0 00428±0 00003)

No of step	Tempe-rature (℃)	^{40}Ar ($\times 10^6$ cm^3/g)	^{36}Ar/^{40}Ar ($\times 10^{-4}$)	^{37}Ar/^{40}Ar ($\times 10^{-3}$)	^{38}Ar/^{40}Ar ($\times 10^{-4}$)	^{39}Ar/^{40}Ar ($\times 10^{-3}$)	^{40}Ar*/ ^{39}Ar$_K$	^{39}Ar$_K$ (%)	Age (Ma)	K/Ca
1	600	2 51	1 644	1 300	0 7917	0 8458	1126	0 4	3178	0 6498
			±0 012	±0 020	±0 0056	±0 0057	±8		±15	
2	700	0 887	0 9956	4 617	1 976	3 193	304 4	0 6	1505	0 6909
			±0 0094	±0 073	±0 014	±0 009	±0 8		±8	
3	800	3 15	0 4658	2 842	2 866	4 649	212 3	3 0	1166	1 635
			±0 0037	±0 026	±0 019	±0 009	±0 4		±6	
4	900	6 65	1 199	3 327	3 512	5 538	174 3	7 5	1005	1 664
			±0 010	±0 029	±0.024	±0 008	±0 3		±6	
5	1000	9 25	0 1963	4 030	2 598	4 301	231 4	8 1	1242	1 067
			±0 0017	±0 033	±0 018	±0 010	±0 5		±7	
6	1100	1 65	0 1617	5 005	2 476	3 936	253 2	13 3	1324	0 7857
			±0 0021	±0 040	±0 017	±0 009	±0 6		±7	
7	1200	27 3	0 1169	8 530	3 199	4 857	205 6	27 1	1139	0 5687
			±0 0018	±0 060	±0 021	±0 010	±0 4		±6	
8	1300	30 6	0 1310	11 51	3 451	5 061	197 4	31 7	1105	0 4389
			±0 0023	±0 08	±0 023	±0 012	±0 5		±6	
9	1500	9 60	0 1394	13 17	2 849	4 201	237 9	8 2	1267	0 3182
			±0 0028	±0 10	±0 020	±0 010	±0 6		±7	

Sample S-7 (0 0951 g, J=0 00434±0 00003)

No of step	Temperature (℃)	^{40}Ar ($\times 10^6$ cm^3/g)	$^{36}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{37}Ar/^{40}Ar$ ($\times 10^{-3}$)	$^{38}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{39}Ar/^{40}Ar$ ($\times 10^{-3}$)	$^{40}Ar^*/^{39}Ar_K$	$^{39}Ar_K$ (%)	Age (Ma)	K/Ca
1	600	9 33	0 8261	2 369	0 3080	0 5149	1902	1 1	4014	0 2166
			±0 0144	±0 045	±0 0272	±0 0107	±40		±35	
2	700	2 05	0 6792	2 270	0 8618	1 286	763 1	0 6	2636	0 5659
			±0 0066	±0 026	±0 0052	±0 006	±3 8		±12	
3	800	4 43	2 449	4 985	2 811	3 785	245 4	3 8	1308	0 7585
			±0 016	±0 034	±0 015	±0 007	±0 5		±7	
4	900	5 76	0 2517	5 119	5 146	8 160	121 7	10 6	765 1	1 593
			±0 0050	±0 047	±0 036	±0 041	±0 6		±5 4	
5	1000	1 06	0 1605	4 904	5 122	7 885	126 3	18 8	788 5	1 607
			±0 0027	±0 032	±0 027	±0 015	±0 2		±4 6	
6	1100	12 1	0 1781	7 471	4 475	6 089	163 6	16 6	968 0	0 8143
			±0 0034	±0 047	±0 024	±0 014	±0 4		±5 5	
7	1200	12 1	0 3143	12 23	5 073	5 796	171 4	15 8	1003	0 4733
			±0 0042	±0 08	±0 028	±0 013	±0 4		±6	
8	1300	30 4	1 159	7 975	3 417	3 778	256 2	25 8	1349	0 4730
			±0 008	±0 050	±0 020	±0 009	±0 6		±7	
9	1500	40 4	1 244	7 436	0 8908	0 7674	1265	7 0	3375	0 1025
			±0 009	±0 053	±0 0050	±0 0041	±7		±13	

± in values are errors of one standard deviation

^{36}Ar, ^{37}Ar, ^{39}Ar and ^{40}Ar values in this table are not corrected for interference Ar isotopes derived from K- and Ca

Ages and other values have been corrected for interference Ar isotopes by using the following values, $(^{40}Ar/^{39}Ar)_K = 0\ 06336 \pm 0\ 00616$, $(39^{Ar}/^{37}Ar)_{Ca} = 0\ 0007328 \pm 0\ 0000178$, $(^{36}Ar/^{37}Ar)_{Ca} = 0\ 0004228 \pm 0\ 0000821$

(1) $^{40}Ar^*$ and $^{39}Ar_K$ mean the radiogenic ^{40}Ar and K-derived ^{39}Ar, respectively

(2) Ages were calculated by using the following constants $\lambda_e = 0\ 581 \times 10^{-10}/y$, $\lambda_\beta = 4\ 962 \times 10^{-10}/y$, $^{40}K/K = 1\ 167 \times 10^{-4}$ (STEIGER and JAGER, 1977)

(3) K/Ca ratios were calculated from $^{39}Ar_K/^{37}Ar_{Ca}$, where $^{37}Ar_{Ca}$ means Ca-derived ^{37}Ar

4. Results and Discussion

Experimental results are shown in Table 1 and Fig 2. Since the data do not lie on straight lines in the isochron plots, the isochron plots are not shown for all samples.

For metamorphic rocks, S-1 and S-2, the typical excess Ar pattern (U-shape) is observed in the age spectra (Fig 2) (McDOUGALL and HARRISON, 1988). Old ages in lower and higher temperature fractions exceed the age of the earth Although the last intense metamorphism at about 2.5 Ga has been reported to have high temperature of 650°C (BLACK and McCULLOCH, 1987), there are no indications of age of about 2.5 Ga for present samples The minimum ages of about 1000 Ma are observed in the 1000° C fraction for S-1 and about 2000 Ma in the 900–1200° C fractions for S-2, which means that the last metamorphic events might have occurred at a time younger than the minimum ages

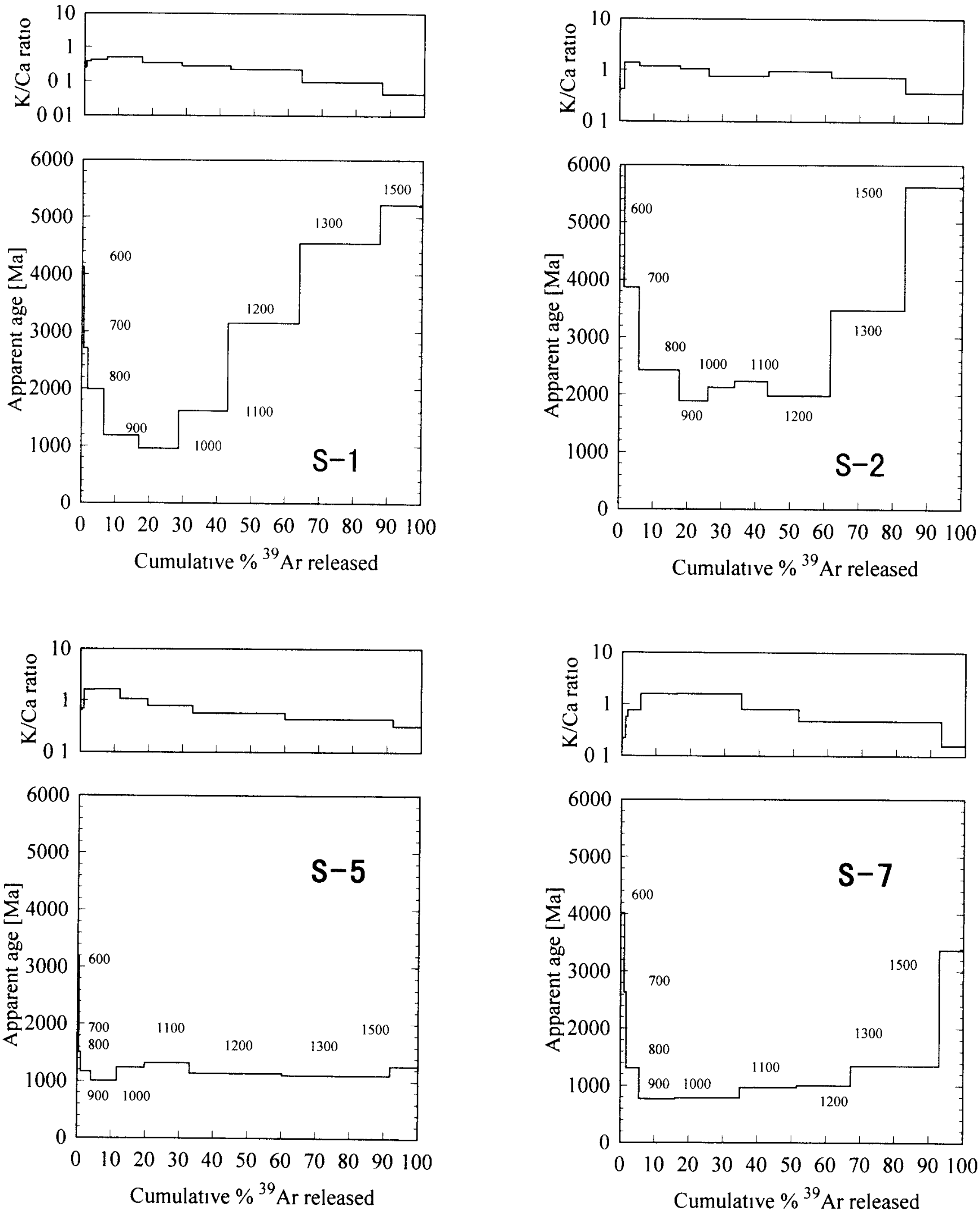

Fig 2 *^{40}Ar-^{39}Ar age spectra and K/Ca plots for samples S-1, S-2, S-5 and S-7*
The upper part is a K/Ca plot and the lower part is an age spectrum for each sample K/Ca ratio varies reflecting Ar gas degassing from different minerals or sites in the sample Errors are included in age bands in the age spectrum and not illustrated in the K/Ca plot Numerical figures in the age spectrum indicate the Ar degassing temperatures in Celsius degrees (℃) identified as the temperature at the top of Mo crucible

S-2 shows the age of about 2000 Ma in the 900-1200°C fractions Since these fractions account for 44% of the released ^{39}Ar, this age may have some geological significance in spite of the minimum age However, no previous Rb-Sr, U-Pb and Nd-Sm works have shown the age of 2000 Ma (JAMES and BLACK, 1981, BLACK and McCULLOCH, 1987; SHERATON *et al.*, 1987, BLACK *et al.*, 1992, OWADA *et al.*, 1994, TAINOSHO *et al.*, 1997) Recently, SUZUKI reported a CHIME age of 2046 Ma for a monazait sample from Mt Riiser-Larsen (ASAMI *et al.*, 1998). This also suggests a possibility that there might have been a thermal event around 2000 Ma in the Mt Riiser-Larsen area

For dolerite samples, S-5 and S-7, features indicating the occurrence of excess Ar are observed in the age spectra though they are not so clear as those of S-1 and S-2 Relatively uniform ages of about 1000–1100 Ma are recognized for S-5 in the 800, 900, 1200 and 1300°C fractions (69.3% released ^{39}Ar) and those of about 800–1000 Ma for S-7 in the 900–1200°C fractions (61 8% released ^{39}Ar), respectively (Fig 2). Total fusion ages are 1183±6 Ma and 1432±7 Ma for S-5 and S-7, respectively, which are consistent with previous K-Ar results (1170±50 Ma and 1400±50 Ma) for another basalt from Mt Riiser-Larsen (UENO, 1995)

In Enderby Land, there are many dykes called Amundsen dykes which have two different ages, 1190±200 Ma and 2350±48 Ma, determined by the Rb-Sr method (SHERATON and BLACK, 1981, BLACK and JAMES, 1983) Moreover, an age of 1087 Ma for pegmatite (SHERATON *et al.*, 1987) and of 1073 Ma for monazite (BLACK and JAMES, 1983) have been reported in the Napier Complex. Those igneous activities are considered to have been correlated with the activity of the Rayner Complex, situated to the south of the Napier Complex, since the age of the Rayner Complex has been inferred to be about 1100 Ma (BLACK and JAMES, 1983). Thus the studied dolerites may be part of the Amundsen dykes.

If we adopt these ages for dolerite samples, the positions of the virtual geomagnetic pole (VGP) investigated from paleomagnetic studies for the same samples are not consistent with the results expected from other places in Gondwana Land. Detailed discussions about paleomagnetic studies were performed in ISHIKAWA and FUNAKI, (1997, 1998).

5. Summary

Although the occurrence of excess Ar has been observed in samples from the Napier Complex, an age of about 2000 Ma for a gneiss and ages of about 800–1100 Ma for dolerites have been conjectured These results are preliminary ones and we need more ^{40}Ar-^{39}Ar geochronological studies to establish a more accurate relationship with paleomagnetic and geological studies

Acknowledgments

We wish to thank Prof. I KANEOKA and members of the Radio Isotope Centre, University of Tokyo, for providing experimental facilities We also thank the members of the Oarai Branch IMR, Tohoku University, for the neutron irradiation at Japan

Material Testing Reactor.

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(Received Fubruary 18, 1998, Revised manuscript accepted May 6, 1998)